Medical image quantification

Quantification

… is calculating "useful" metrics from a medical image.

Useful metrics can range from quality control measurements (e.g. MTF, DQE) to the location and suspected malignancy of lesions in mammograms.

Image analysis tools

- Removing a background function
- Finding and following closed perimeters
- Simplifying perimeters
- Surrounding and skeletonizing objects
- Characterizing topology and shape
- Characterizing texture
- Detecting/locating objects by template matching
- Detecting lines, arcs, circles

Image analysis tools – removing background

- To correct for non-uniform exposure
  - e.g. artifacts caused by film-screen grids
- To correct for uniform object producing non-uniform signal
  - e.g. bias correction in high-field MRI
- To correct for non-uniform signal due to non-uniform object thickness
  - e.g. non-uniform breast compression in mammography

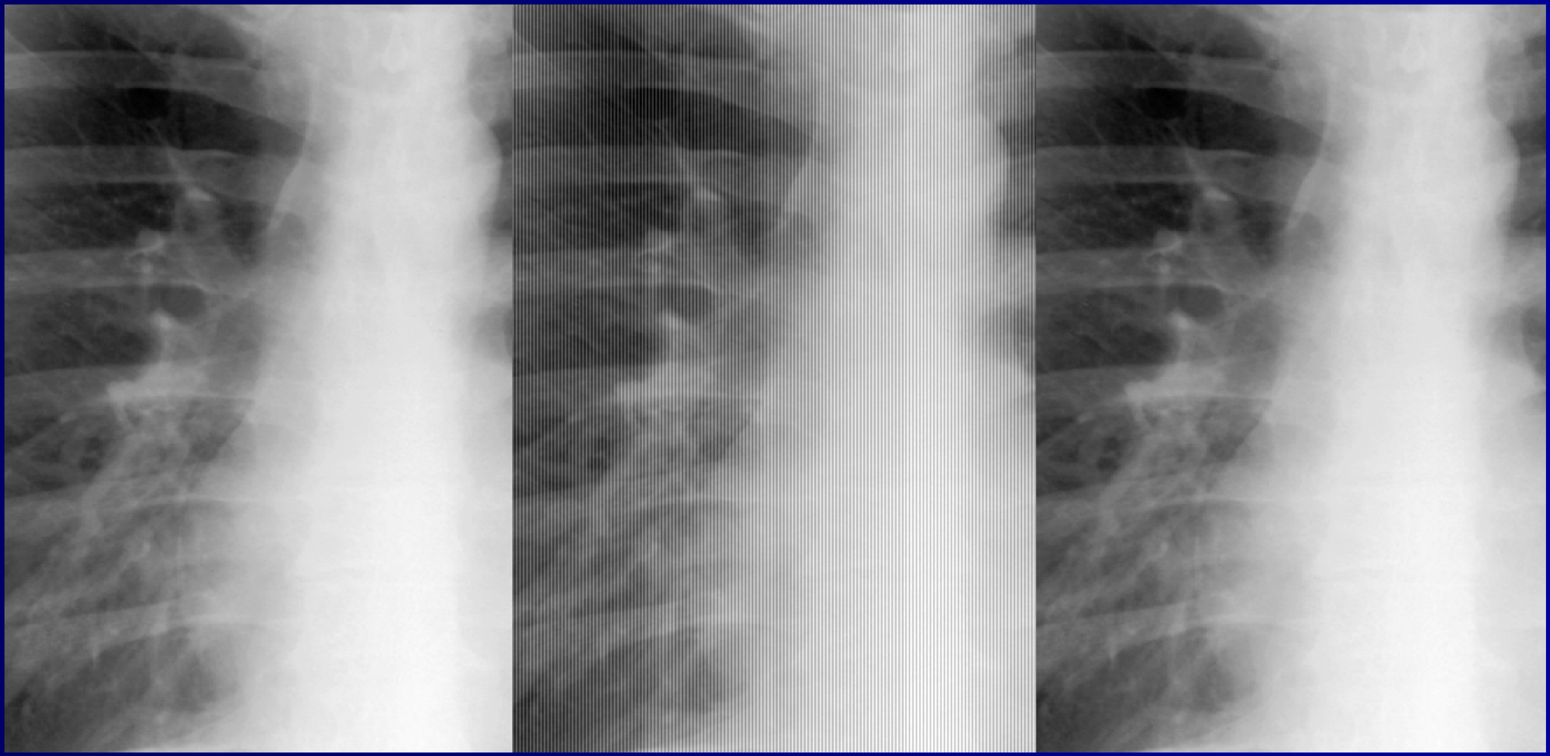
Image analysis tools – removing background

Define the background function:

- As specific frequency components
  - This approach requires treating the background function as linear and shift-invariant.
- By estimating a spatially-varying correction function from the image data
- By defining a model-based background

Image analysis tools – removing background

Original with simulated grid recovered



Removal of grid shadows: FFT of corrupt image shows a high frequency spike. Verify that spike corresponds to grid and clip it.

Image analysis tools – removing background

Intensity bias exists in each simulated MRI slice, and varies in scale from slice to slice.

Use samples from corners of each slice to fit a background function.

Suppression of bias ✍

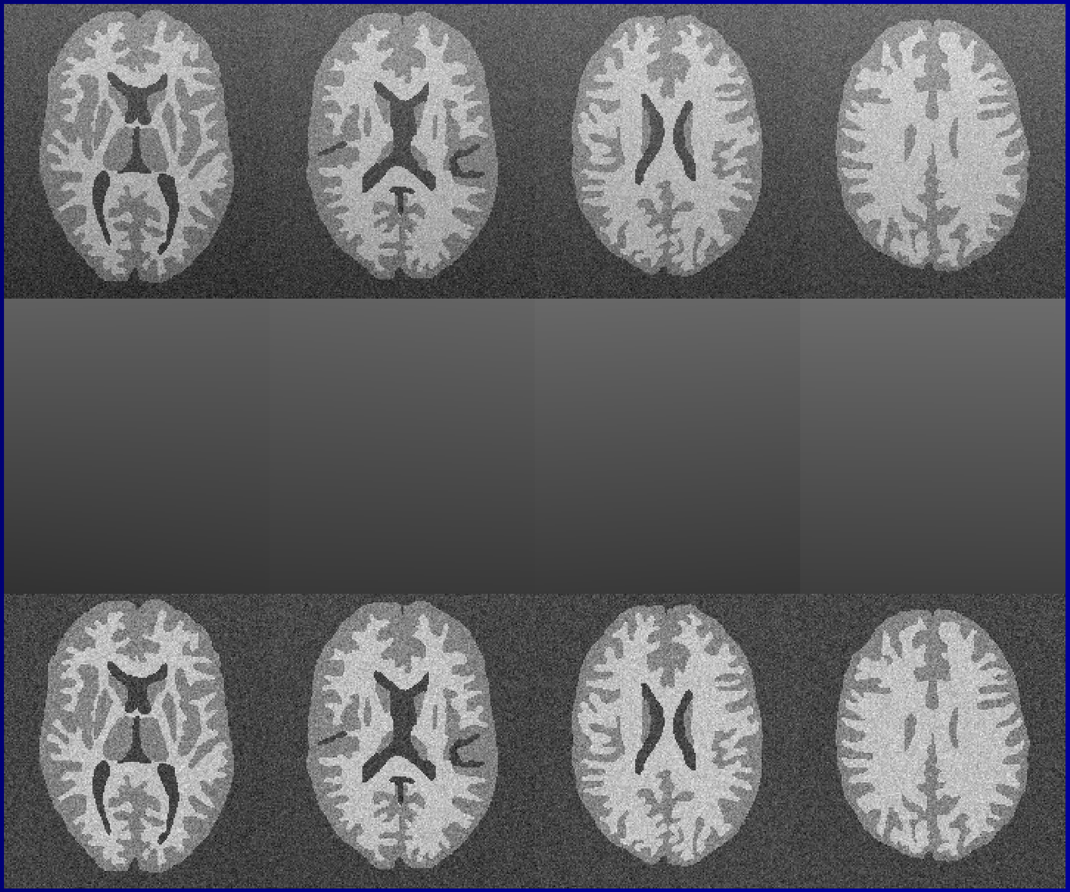


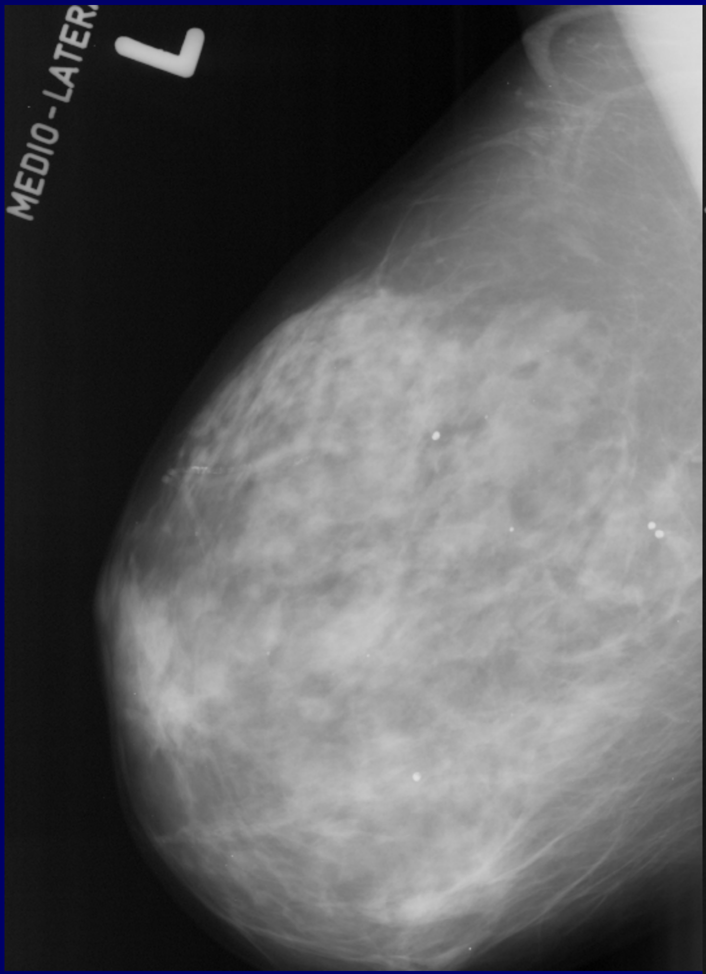
Image analysis tools – removing background

In mammography, the breast margin is not compressed to the same thickness as the central portion, therefore film exposure is increased.

A correction factor that models the expected curvature at the margins allows adjustment of the intensity based on the distance from the central portion.

Image analysis tools – removing background

Raw



Thickness correction

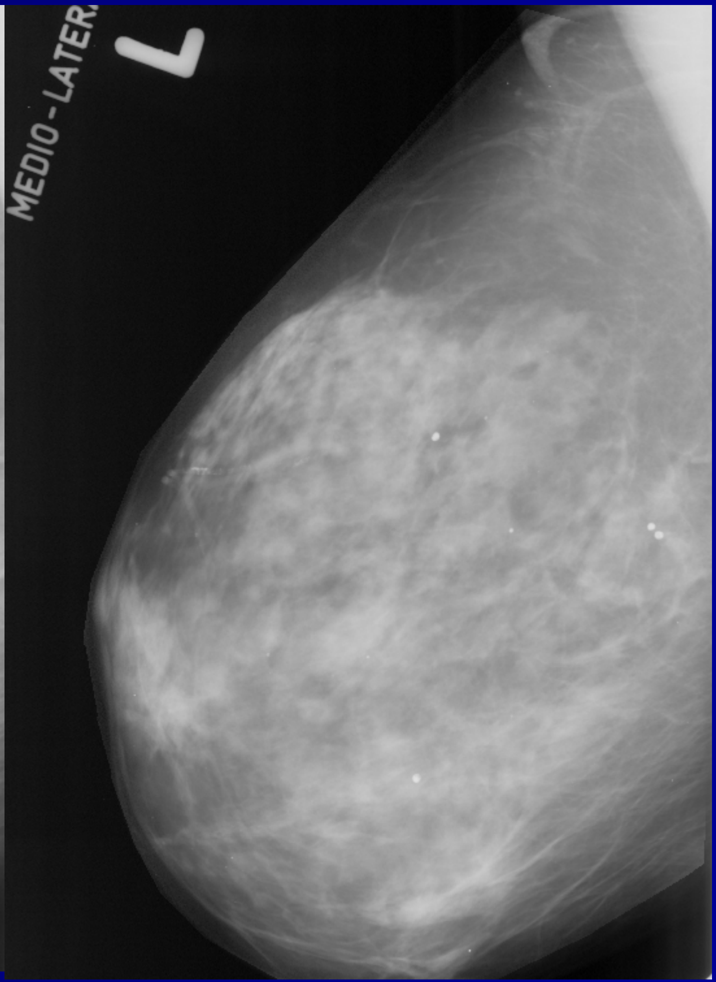


Image analysis tools – finding and following perimeters

- Intensity differences distinguish background from foreground - essentially treating data as binary.
- A starting point is required for each perimeter.
- Neighboring pixels are checked for greatest gradient, i.e., delta brightness/center-to-center distance.
- A directional bias is used to select between equal-gradient choices -- usually minimizing the change in angle between the previous, current and candidate pixel.

Image analysis tools – finding and following perimeters

0	1	1
0	P	1
0	P	0

P denotes perimeter pixel

Next gradients are all = 1

Weighted by distance, North and East are best candidates.

Angle between current P pixels and North is 180 degrees, P and East is 90 degrees. Next perimeter point is best assigned to North.

Image analysis tools – finding and following perimeters

Image is made binary using threshold.

A point on the edge is selected.

A closed contour is formed, which can later be filled to make a mask.

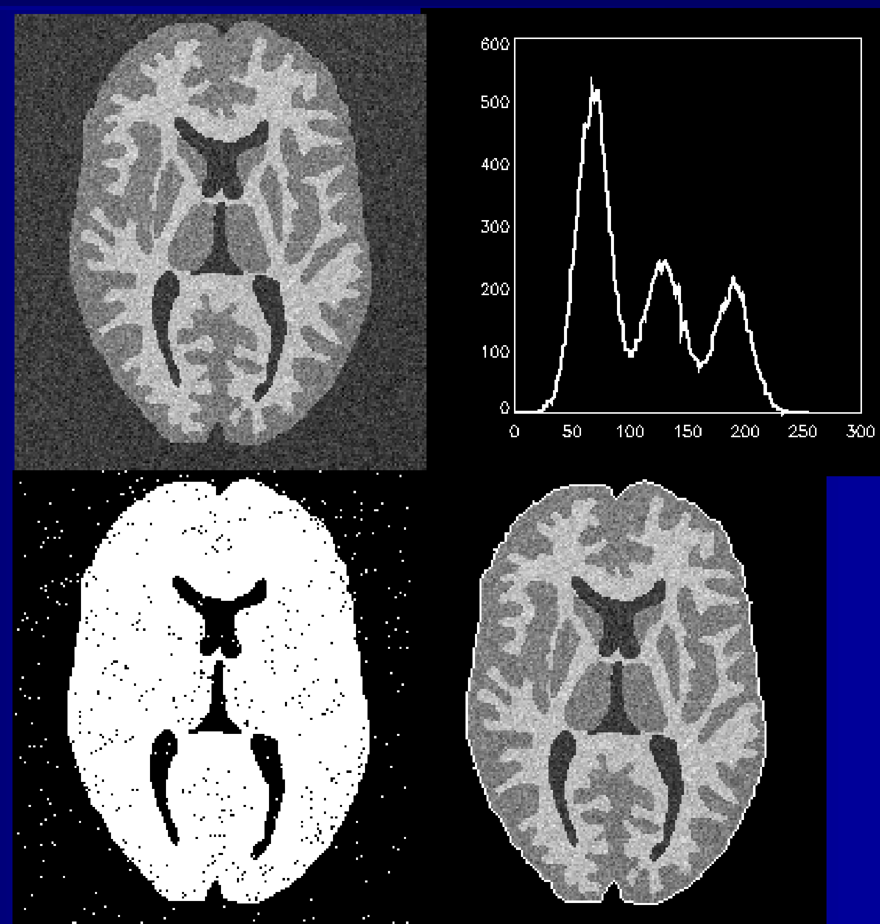


Image analysis tools – simplifying perimeters

- Increasing the size of the neighborhood to be searched while enforcing directional bias attempts to allow the perimeter finder to "look ahead" in order to maintain minimum angle change. This will bridge small indentations in a boundary.
- A convex hull looks ahead with no maximum distance.

Image analysis tools – simplifying perimeters

Ordinary perimeter

Convex hull

Image analysis tools – surrounding

"Custering" produces the surround of an object.

- erode the original
- dilate the original
- perform an exclusive OR of those two results

Also makes a border for interior holes.

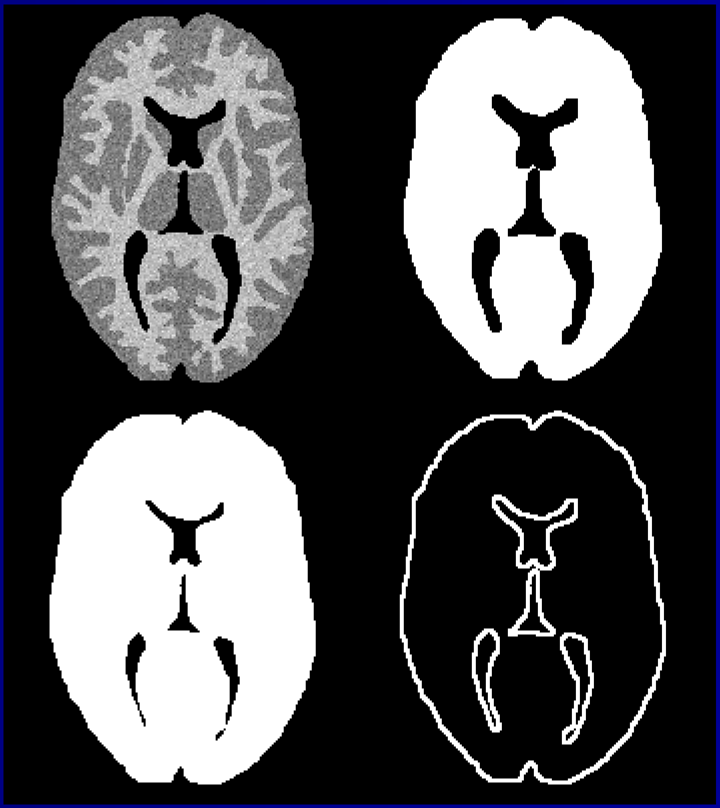


Image analysis tools – skeletonizing

Skeletonizing is a special erosion method that removes pixels EXCEPT those that would divide regions. If neighbors touching a central pixel do not touch each other, the central pixel cannot be removed.

Endpoints of skeleton lines are found by searching for points having only one neighbor.

Branches are found by searching for points with more than two neighbors.

1	1	1
	1	

Can remove

1		1
	1	
		1

Can not remove

Image analysis tools – skeletonizing

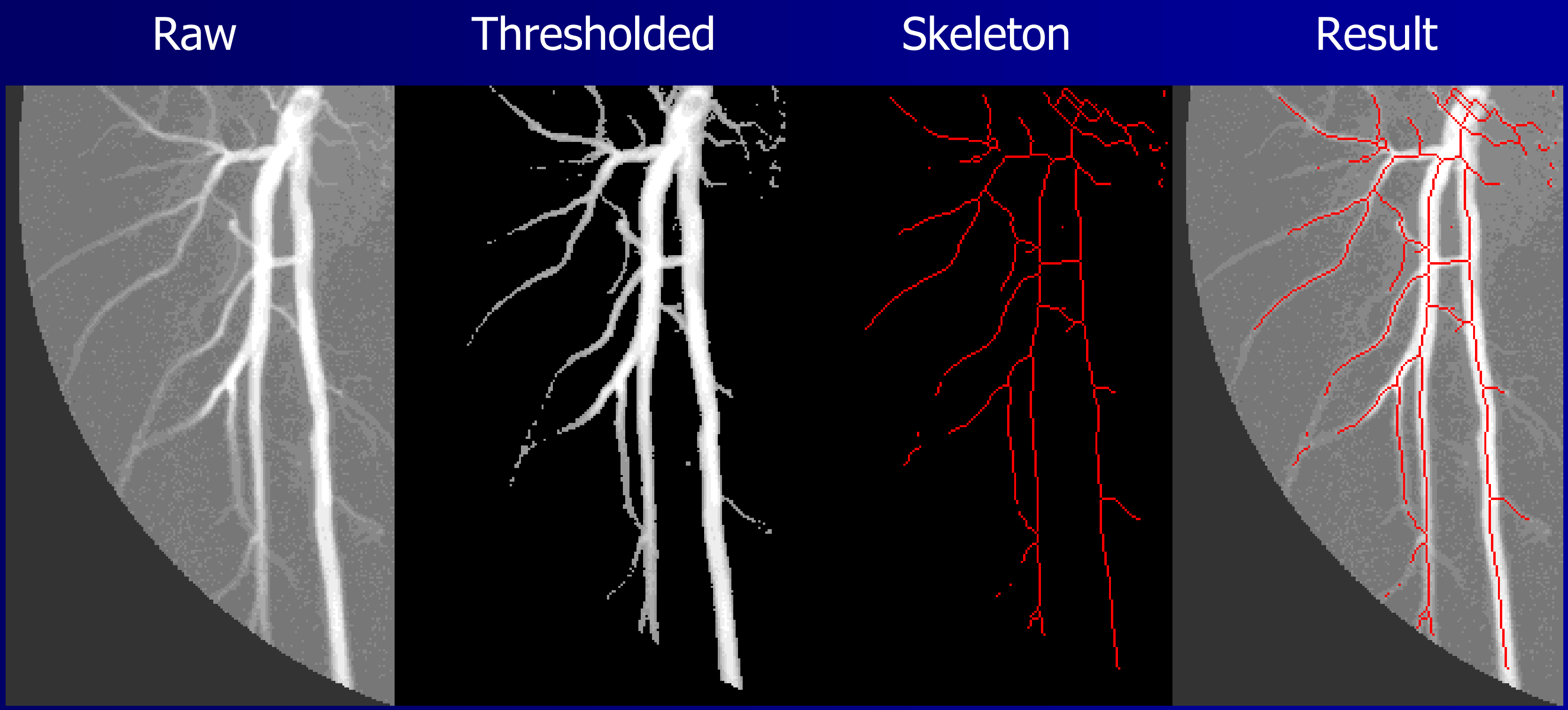


Image analysis tools – topology

Features or objects are topologically the same if a "rubber block" representation of one can be stretched to match the other object.

The Euler characteristic is a number used to describe the topology of an object.

E = C - H, where C is the number of connected components and H is the number of holes in them.

for a 2D object, E = #vertices - # edges + # pixels
for a 3D object, E = #vertices - #edges + #faces - #cubes
(only count an edge, vertex, or face once)

Image analysis tools – shape

2D shape descriptors

Form factor	: 4pi * area / perimeter^2
Roundness	: 4 * area / (pi * max diameter^2)
Aspect ratio	: max diameter / min diameter
Elongation	: fiber (skeleton) length / fiber width
Curl	: length / skeleton length
Convexity	: convex perimeter / perimeter
Solidity	: area / convex area
Compactness	: sqrt(4 * area/pi) / max diameter
Extent	: Net area / area of bounding rectangle

Image analysis tools – shape

Form factor : 4pi * area / perimeter^2
Aspect ratio : max diameter / min diameter

Figure 45. *Variations on a shape produced by erosion/dilation and by horizontal stretching. The numeric values for formfactor and aspect ratio (listed below) show that stretching changes the aspect ratio and not the formfactor, and vice versa for smoothing the boundary.*

Shape	*Formfactor*	*Aspect Ratio*
A	0.257	1.339
B	0.256	2.005
C	0.459	1.294
D	0.457	2.017

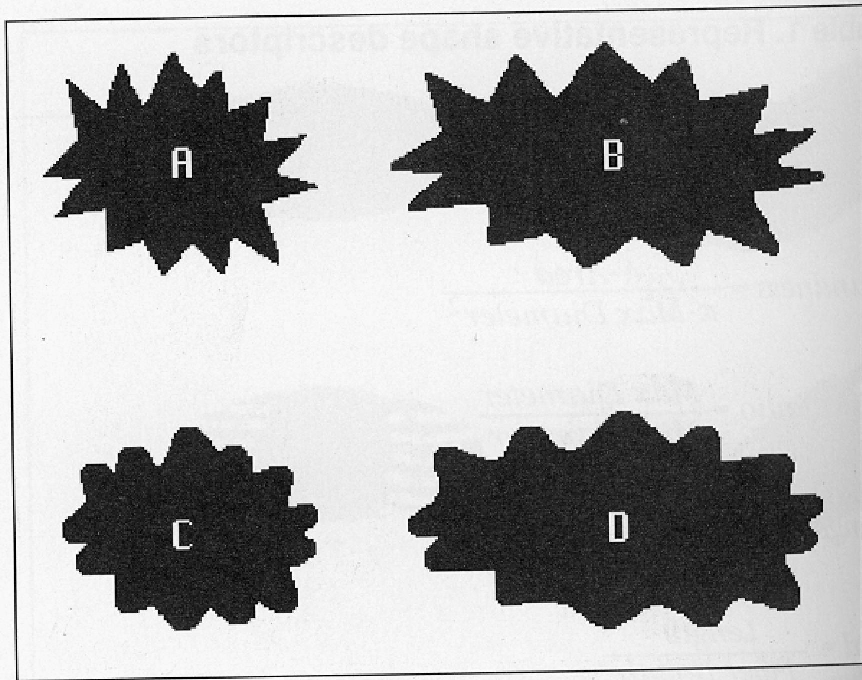


Image analysis tools – shape

Roundness	: 4 * area / (pi * max diameter^2)
Convexity	: convex perimeter / perimeter
Solidity	: area / convex area
Compactness	: sqrt(4 * area/pi) / max diameter

Figure 46. *Another set of four related shapes with the numeric values for their measured shape parameters.*

Shape	*Roundness*	*Convexity*	*Solidity*	*Compactness*
A	*0.587*	*0.351*	*0.731*	*0.766*
B	*0.584*	*0.483*	*0.782*	*0.764*
C	*0.447*	*0.349*	*0.592*	*0.668*
D	*0.589*	*0.497*	*0.714*	*0.768*

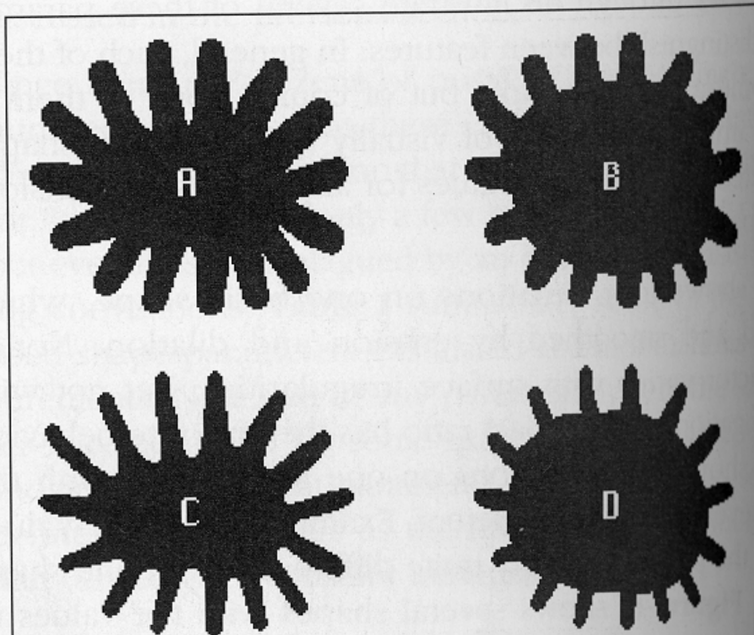


Image analysis tools – shape

Curl : length / skeleton length
Extent : Net area / area of bounding rectangle

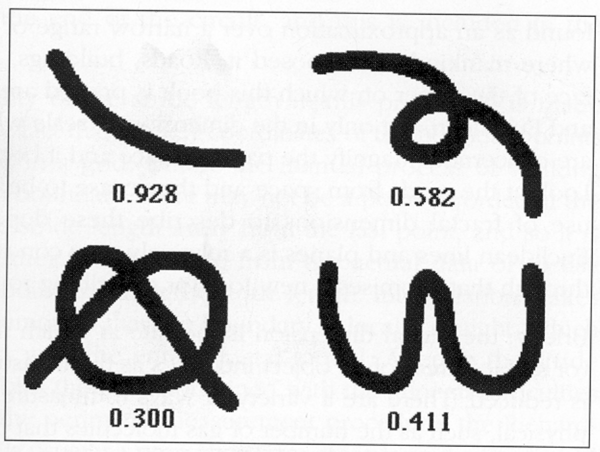


Figure 47. *Four features with different values of curl, indicating the degree to which they are "curled up."*

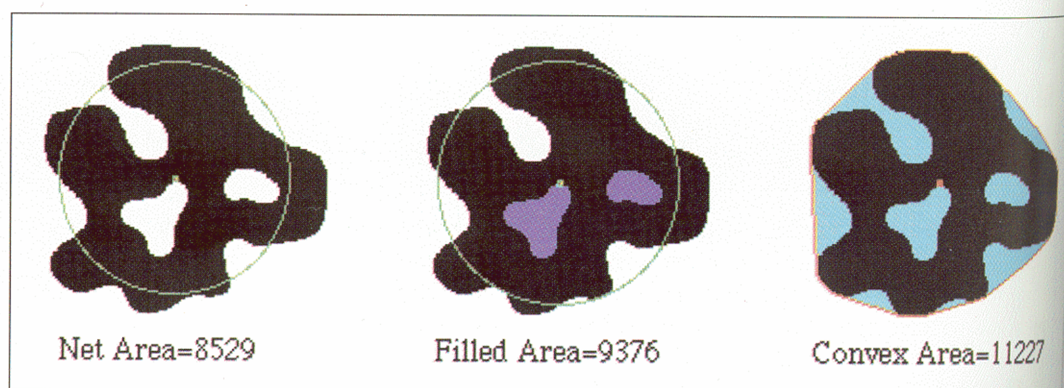


Figure 29. *Comparison of different area measurements of a feature, shown in pixels.*

Image analysis tools – shape

Using shape descriptors for classification

- Measure area
- Measure form factor

Figure 59. *An example of four small training classes of different groups of features. Two of these are the same shape but have different sizes, while the others have an intermediate size and different shapes. No single measurement parameter uniquely discriminates them.*

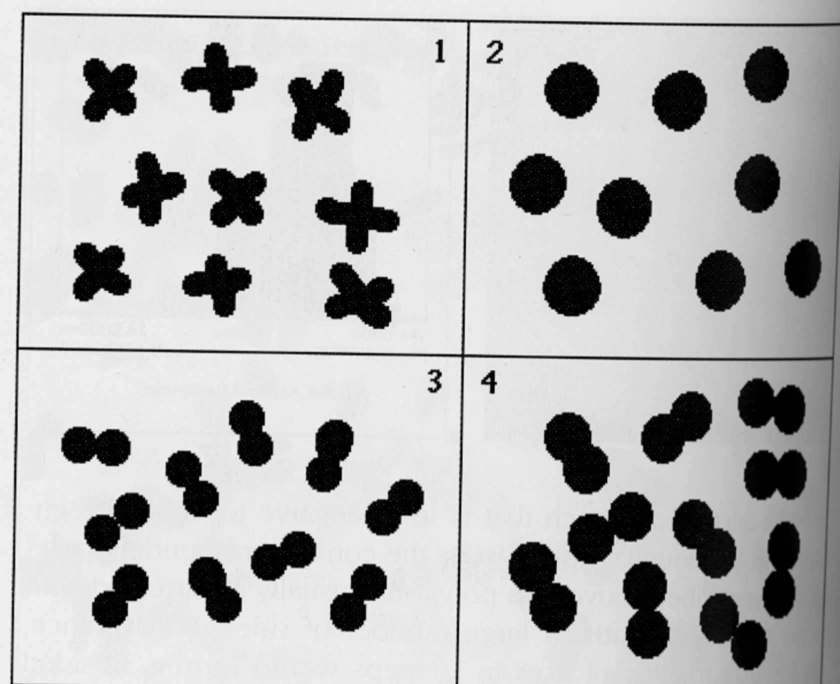


Image analysis tools – shape

Using shape descriptors for classification

Figure 60. *A plot of the measured values of area and formfactor for the features in Figure 59, color coded according to identity. The outlined points are unknowns from Figure 61, and not part of the training population. For each group, the mean value is shown, and an ellipse drawn with major and minor axes equal to two standard deviations of each measured parameter.*

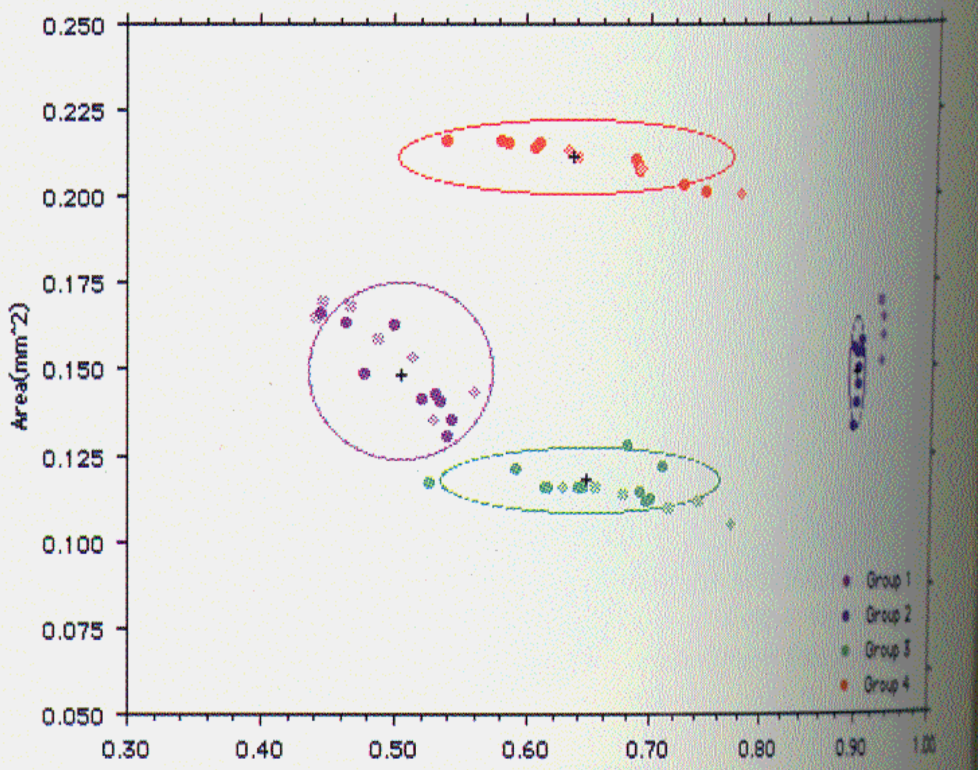


Image analysis tools – shape

Using shape descriptors for classification

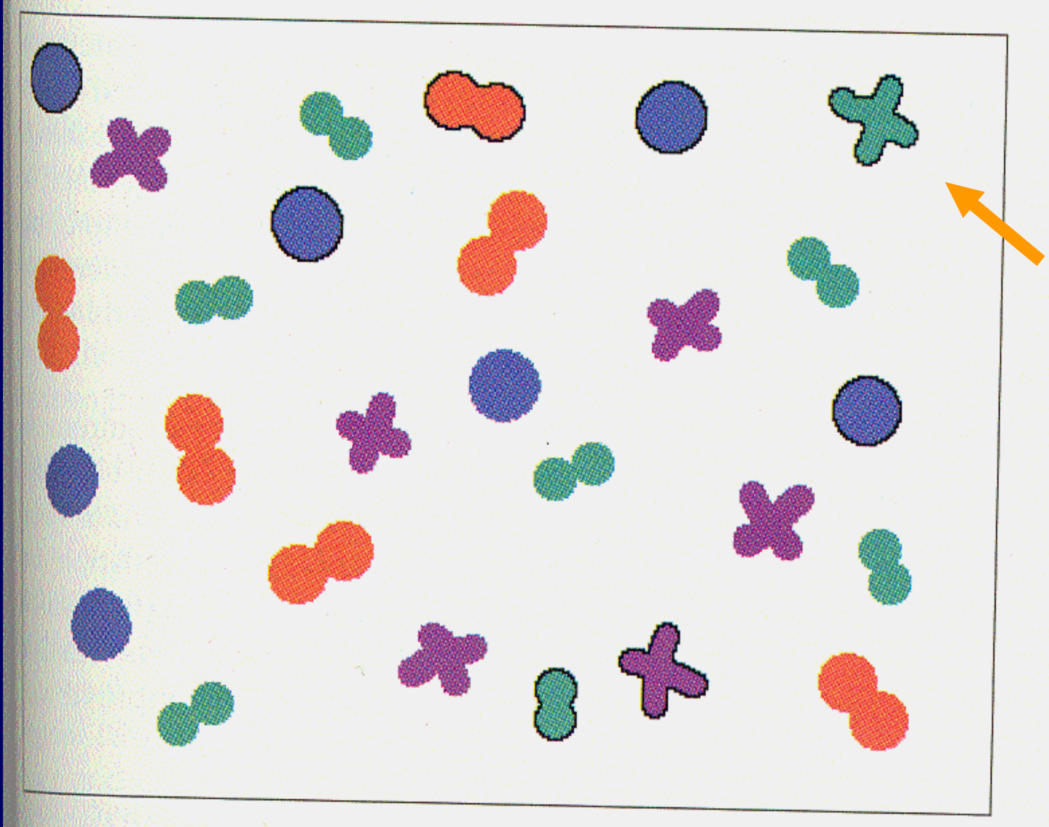


Figure 61. *An example of unknown features to be identified using the plot in Figure 60. The color codes identify the class whose mean is closest to the measured area and formfactor of the unknown. A black outline indicates that the feature does not lie within the two-standard-deviation ellipse.*

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Image analysis tools – texture

Fractal dimension is often used to characterize the structure of an object.

The fractal dimension of a perimeter can be described in several ways. One such is the Minkowski method – measure the area swept out by a circle following the path.

Plotting the measured area as a function of circle radius on a log-log scale is a straight line whose slope is the fractal dimension.

Image analysis tools – fractal dimension

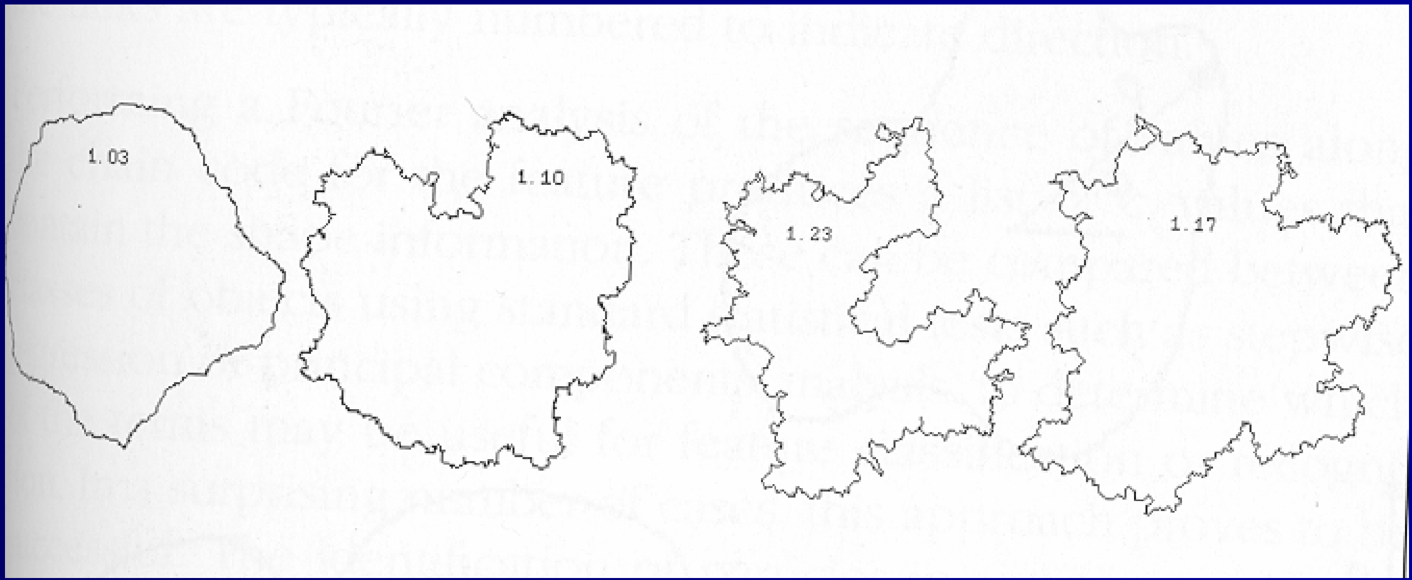
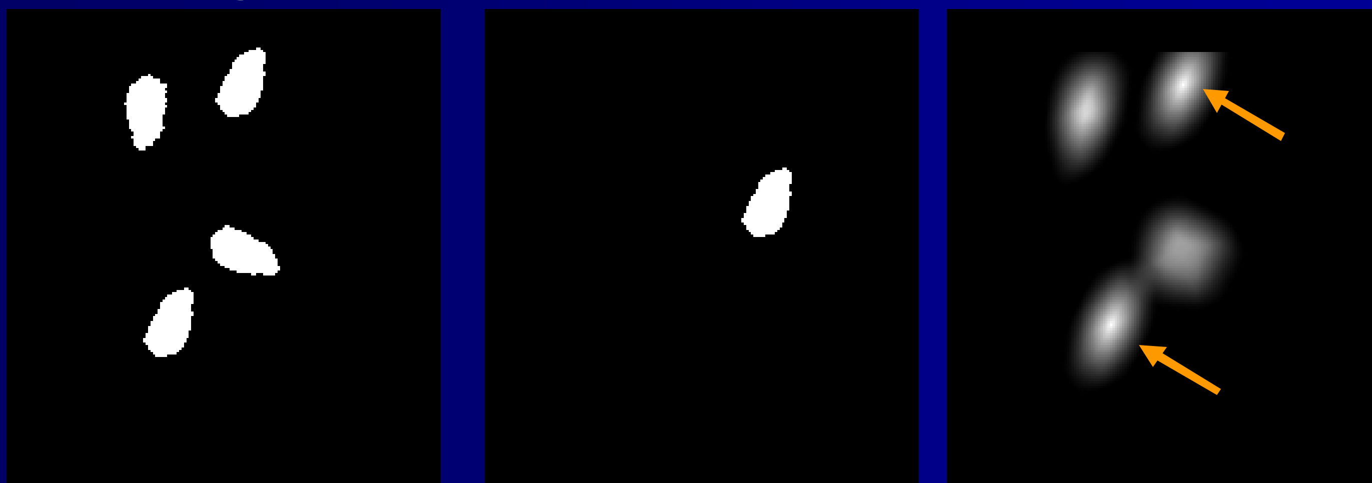


Image analysis tools – detecting and locating objects

- For determining whether (and where) a target exists in an image or volume.
- A target pattern is shifted to every location in the image, and the target and corresponding image pixels are multiplied. The total (cross-correlation) is stored at that position.
- Can be used to find letters in text, find fiducial marks in images, etc.

Image analysis tools –
detecting and locating objects

image matched filter cross-correlation



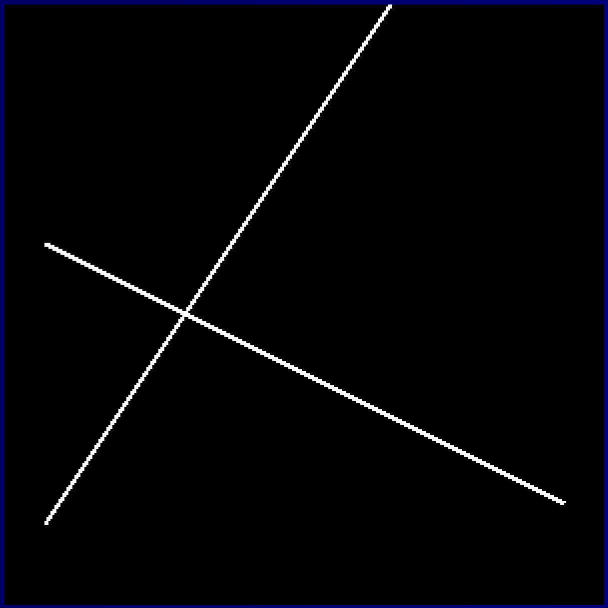
Peaks in cross-correlation image indicate the location of best matches.

Image analysis tools – detecting lines, arcs and circles

- For estimating edges from interrupted or sparse edge points.
- The Hough transform makes use of the fact a line (in 2D) is defined by 2 parameters. Each point in the image is transformed to a slope and intercept pair, forming a histogram of pairs in the transform space. Peaks in the transform space identify the dominant lines.
- As circles and arcs can also be described parametrically, a Hough transform can also be used for them.

Image analysis tools – detecting lines, arcs and circles

A family of lines can pass through each sample point in the image. Accumulating the families results in a peak or peaks in the Hough transform.



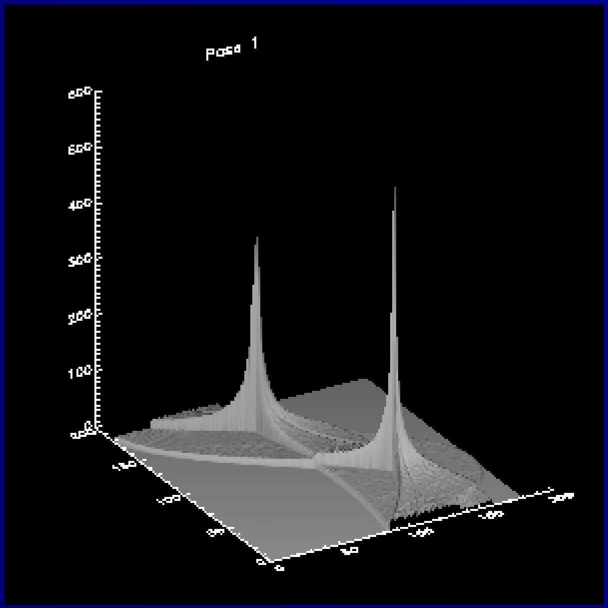


Image analysis tools –
detecting lines, arcs and circles

Each sample point can result from a family of circles of a range of radii. Accumulate the family at a particular radius, and a peak occurs at the center.